The Role of New Grid Technologies
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Introduction

The business environment for utilities has never been more challenging: load growth, competition and cost pressures, regulatory uncertainty, and demands for "high-nines" reliability are all converging. Yet perhaps no trend of past generation has been more challenging than the growing pressure on utilities to respond to issues related to the physical environment. Since the growth of environmental consciousness in the 1970s, businesses and industries of all types have faced growing scrutiny over how their practices affect natural resources and communities. And few activities in our entire economy affect the environment as profoundly as the production and delivery of electric power. Utilities have come under steadily rising pressure to reduce their air emissions, water use and footprint on the landscape. The future shape of of the electric power industry is still far from certain -- yet we can be confident that this environmental pressure on utilities will only intensify. How can this industry shrink its physical and environmental footprint, while at the same time meeting the pressures of increasing demands brought about by a growing population and a steadily electrifying economy?

Some believe this challenge is insurmountable. Over the past few years, a fashion of thought has arisen that the power grid as we've known it for the past century may become obsolete, not unlike the canals and street railways of the 19th century. When first put forth a decade or more ago, this idea was dismissed as a radical notion. Yet it gained credence in the mid-to-late 1990s as regulatory reforms deregulated power supply, leading to explosive entrepreneurial interest in new generation technologies. Some policymakers were likewise profoundly attracted to the distributed generation paradigm as well. It offered an attractive prospect: by distributing power production closer to customer loads, it would be possible to reduce or eliminate the need for controversial expansions to the power grid. Distributed power could also improve reliability for a small fraction of highly demanding end users without the need for comprehensive and costly system upgrades. Over the past decade, the "siliconization" trend has continued apace -- that is, the pervasive spread of highly sensitive microprocessors that are dependent upon highly reliable power supplies of uniform power quality. The notion spread among industry observers that the traditional utility grid was simply not up to the challenge of supplying the power requirements of life in a modern information-based economy.

The role of new technologies

The reality of DG technology development has lagged behind its promise. However, as a result of a prolonged decline in grid investment, real problems have come home to roost for utility consumers and the nation. As a result, industry observers have begun rethinking the likely evolution of the industry. Experts increasingly recognize that -- even with a growing role for distributed resources -- the future electric industry model will remain network-based; while DG can furnish many attractive customer-level solutions, only a stronger grid can address system-level problems. As in other network industries such as telecommunications and natural gas, the grid remains the key to a range of important objectives: economical sharing of reserves, high levels of system redundancy and fuel diversity, and the ability to support robust, wide-area competition among generating resources.

The key challenge facing the industry is not how to move beyond the physical limitations of a grid-based system. Rather, it is how to strengthen the grid within the physical limitations of today's environmental and land use values. The Achilles' heel of the grid -- indeed, the attribute that fuels ongoing interest in DG -- is that its performance is limited by physical factors inherent in the physical materials, the "stuff" that makes up the grid. These factors include the *thermal capacity* of the system's elements, e.g., aluminum and copper lines and transformers, as well as the *voltage stability* of the system (the grid's interconnectedness subjects users to power disturbances beyond their immediate area). A small but growing segment of customers place a high premium on ensuring the highest levels of reliability and power quality. For certain of these customers, in fact, the cost of electricity is incidental; reliability and power quality have become the principal attribute on which they choose supply arrangements.

New and emerging technologies based on advances in materials underlie a new generation of power grid solutions that can improve the power grid's total thermal capacity and stability. These advances range from FACTS and HVDC applications, based on new and more powerful and cost-effective high-voltage power electronics, to new overhead lines based on high-capacity ceramics-reinforced conductors, to new types of transformer oil dielectrics that can boost the capacity of substations by 10 percent or more. The list of potential innovations in the power grid is long and growing.

Several of the most exciting new grid technologies are based on advances in the fields of semiconductor-based power electronics and superconductivity, the phenomenon that causes materials to lose all resistance to the flow of electrons and endows them with the ability to carry massive amounts of current. American Superconductor has been involved in the development of two applications -- superconducting magnetic energy storage devices and high-capacity power cables -- that offer particularly important advantages to power grid operators at a time when environmental factors place severe limits on available options. While both are more environmentally friendly than the legacy technologies they replace, they engender system-level performance improvements that result in still more positive environmental characteristics. Interest in the field of superconductivity has grown steadily in recent years, as the long-term development efforts following discovery of so-called "high-temperature superconductors" in the mid-1980s has begun to yield truly commercial applications.

<u>Enhancing grid stability</u>. AMSC deployed the first superconductor-based application in two utility systems in Wisconsin in July 2000. Distributed SMES or "D-SMES" grid stabilization systems effectively provide "shocks and struts for the electricity highway" by injecting combinations of real and reactive power to counteract the destabilizing effects of voltage drops on wide-area grids. Systems have since been deployed in suburban Houston, as well as on the Tennessee Valley Authority grid. In May, the company introduced a new variant of this technology, the D -VAR™ system. Both applications improve grid reliability by quickly dampening out disturbances that can otherwise compound and threaten wide-area stability. Typically packaged in a 55' trailer, these

systems can be distributed throughout a utility network to solve large-scale transmission grid reliability problems. The advantage of mobility allows them to be relocated as system needs change. Each unit responds instantaneously to grid disturbances, delivering precise amounts of reactive power, measured in volt-amperes reactive (VARs), to mitigate the kinds of voltage stability and low-voltage problems that can result in blackouts and brownouts in transmission grids.

These D-SMES and D-VAR applications illustrate how advanced technology can offer innovative, flexible and environmentally benign ways to extract much higher performance from existing power lines. These systems can be highly cost-effective relative to traditional solutions. (A multiple-unit D-SMES system installation on the Wisconsin Public Service Company grid in July 2000, for example, solved a stability problem at a cost of under $5 million that would have required a $12 million line upgrade, not to mention several years, using the conventional approach.) At a time when building new capacity is both costly and time-consuming, the cheapest capacity of all is in the existing capacity of overhead lines that cannot be used because of grid stability concerns. Today, to illustrate, the typical power line in the United States is operated at about 35% of its annual thermal capacity. Adding mobile power reliability systems around the grid represents a strategy that can achieve tremendous financial leverage for utilities, improve overall system reliability for users, and maximize the benefits of competition for market participants.

<u>Boosting grids' thermal capacity</u>. Meanwhile, the first demonstration of a superconducting cable system in a live utility grid is ongoing in Detroit. At a substation on the Detroit Edison system, AMSC's strategic alliance partner Pirelli Cables & Systems, the world's largest power cable manufacturer, has replaced nine copper power cables with a new type of high-capacity cable that carries three times more power than the copper cable it replaces. At the core of the cable is a new type of HTS wire that is rated to carry over 100 times more power than a similarly-sized copper wire. The new cable was snaked through is designed so that it can be retrofit into existing underground ductwork. Conducted under the auspices of the U.S. Department of Energy's Superconductivity Partnership Initiative, the project also includes American Superconductor, EPRI and Linde A.G. as participants. Following further trials, it is expected that the new cable could be deployed commercially on utility systems within the next few years.

Initial applications of the new cable are expected to be in dense urban centers where much of today's load growth is concentrated. Urban utilities could use this strategy to literally multiply the capacity of existing rights-of-way without costly excavation and disruption in heavily trafficked downtown areas. In large "mega-cities" emerging around the world, a robust delivery system will remain an absolute necessity because of the high financial and social costs of power disruptions and the many local obstacles to siting new generation.

Beyond retrofits of existing conduit banks, HTS cable could be used to achieve other goals in urban delivery networks. By feeding power-dense urban cores with high-current superconducting cables, utilities could remove power substation transformers and relocate them on the periphery of the city, where land costs are lower and environmental issues can be more readily addressed. By freeing up space in the urban core, this strategy could even allow utilities to realize value by redeveloping urban parcels now occupied by power infrastructure. Over time, substations ringing urban centers could be linked with underground HTS cable, ensuring the higher level of reliability being demanded by today's customers. Large sections of urban grids could be operated at low voltages, allowing utilities to avoid the expense and environmental issues associated with major transformer installations.

In time, HTS cable could also form the basis for a powerful new approach to bulk transmission. Due to the physical properties of superconductors (which have modest losses when operated in alternating current or AC mode, but are essentially lossless when carrying direct currents), long-distance transmission may be based on DC cable designs. The wider deployment of DC transmission also makes sense in the context of the sharp pricing differentials that have emerged under today's location-based systems of power pricing. Using high-capacity, efficient and environmentally unobtrusive HTS cable, grid operators could inject large blocks of power directly into congested urban systems with electricity "pipelines" that could occupy abandoned pipelines that once carried other products. These designs could eliminate troublesome electromagnetic fields and avoid the creation of troublesome "loop flows" and "parallel paths" that compromise the rights of third-party grid users, thus overcoming some of the most significant barriers to the siting of conventional overhead AC transmission lines.

New grid technologies: the environmental benefits

The deployment of advanced technologies to bolster the power grid could offer a broad range of important environmental advantages. Here, for example, is a partial list of the environmental benefits that could accrue from wider use of these advanced grid technologies:

- <u>Improved plant dispatch</u>. A strong grid is the key to efficient sequencing of power plants to meet total load requirements. Whether the chosen method of dispatch is cost-based or bid-based, whether bids exclude or include consideration of environmental factors, a strong grid offers the means to assure that the optimal mix of plants can be operated by relaxing the constraint of transmission -- resulting in reduced air emissions and fuel consumption.
- <u>Better reliability and power quality</u>. Improving the reliability and uniformity of power delivered through the grid will lead to a lower incidence of the types of power quality problems that are now estimated, by EPRI, to cost the U.S. economy over $100 billion annually in losses, damages and opportunity costs. Recapturing this lost productivity will also lead to associated environmental gains and reduction in waste.
- <u>A stronger role for renewables</u>. Strengthening the power grid will be critical to assure an enhanced role for renewable energy resources such as wind and solar power. Consumers will not move to remote areas where these resources are abundant; rather, we must develop the means to move these resources to the concentrated urban centers where consumers live.
- <u>More efficient use of investment capital</u>. Improving the strength of the grid can reduce the need to build new generators and, instead, allow more efficient use of existing resources. Unfortunately, in recent years, too much investment capital has flowed to the generating sector, and reserve margins are now projected to exceed 30% in some regions. Many generators can only expect to operate for 100-200 hours per year, and will only survive in a highly price-volatile environment. A stronger grid tying the nation's regional markets together will reduce price volatility

and preclude the need for literally billions of dollars of generation investment, enabling existing generators to operate for more hours and reach broader markets.

- Enable higher-value uses of land corridors. Deploying advanced grid technologies on existing corridors will enable much more efficient use of these valuable parcels. Over time, new transmission technologies will allow the redevelopment of existing land corridors condemned for utility purposes. Too often, transmission corridors consume broad swathes of land and impose upon neighbors with high towers and lines. While these construction techniques enabled utilities to save on first costs in the past, they impose ongoing costs by degrading property values and reducing communities' tax base. In the future, by placing high-current transmission through populated areas in unobtrusive underground pipes, utilities and the communities they serve will be able to monetize the value of these corridors. Such an approach would enable utilities to increase their system capacity and reliability, sell off valuable surplus land corridors, improve the property values of power corridor abutters, and increase the tax base of the communities they serve.
- Reduce losses in the T&D system. New technologies can improve the efficiency of transmission and distribution systems, which are major users of power. Currently, our nation's network of power lines and transformers consumes approximately 8-10% of all kilowatt-hours generated. By using advanced technologies such as superconductor components, DC transmission, utilities will be able to reduce entire stages of power transformation, cut line losses and achieve major fuel savings. Moreover, the fuel savings from better generator dispatch will likely go beyond the efficiency gains achievable in the transmission function itself.
- Reduce utilities' land footprint in high-value urban areas. Power systems occupy a significant footprint in densely-settled urban areas where land values are highest. Through the deployment of higher-capacity smart technologies, utilities and urban planners embracing advanced power design approaches will find ways to shrink or eliminate substations, obviate the need for transformers, shrink the size and intrusiveness of high-voltage land corridors in urban neighborhoods, and open up entirely new visions of urban design.
- Eliminate EMF concerns. Despite a paucity of hard medical evidence, concerns about the medical effects of electromagnetic fields associated with AC power lines remains prominent. Superconducting cable technology can surmount this issue through coaxial designs that literally contain all fields within the pipe assembly that shields the cable, resulting in a power delivery solution with essentially zero environmental impact.

Conclusion

The electrification of a wide range of end uses of energy is a fact of modern life. Looking at the span of the 20th century, it becomes clear that this trend has been associated with major environmental advances; the advance of electrification has brought increased energy productivity, health and longevity, and standards of environmental protection. Yet this trend is threatened by our inability to expand the power grid using conventional approaches. Today there is no question that the electric power industry needs to move to a higher level of technology to surmount its current challenges. In recent years, it was commonly supposed that the tightly-integrated, grid-based system of the 20th century would devolve into a highly decentralized, distributed system in the 21st century. But this vision is based on false premises, and could actually worsen the power system's environmental impacts where citizens live and work. The reality is, the power system of the future will be both more distributed and grid-based. It must become more flexible, more interactive and more intelligent. The grid is and will remain the backbone of the power system, the platform for competition, and the means of balancing and integrating all forms of supply and demand. By taking today's antiquated power grid to the next level of technology and materials, the power industry can inject new value into this system -- while fully respecting today's stringent environmental constraints.

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